CHAPTER IV.

LOCOMOTIVES

This chapter presents the project criteria for locomotives under the Carl Moyer Program. It also contains a brief overview of the locomotive industry, emission inventory, current emission standards, available control technology, potential incentive projects eligible for funding, recommended emission reduction calculations, and estimated cost benefits.

A. Introduction

Over the years, the focus of reducing emissions has been from stationary sources and on-road vehicles (light-, medium-, and heavy-duty). Off-road sources, such as locomotives, also contribute to California's pollution problem but have not been regulated in California until recently, although locomotives have been subject to various locally enforced opacity limits. Federal law prohibits California from setting standards for new locomotives and new engines used in locomotives. Only the USEPA has the authority to regulate emissions from locomotives, and has, in fact, adopted standards that phase-in beginning in 2000.

Participating railroads proposed to USEPA and ARB the establishment of a locomotive fleet average emissions program in the South Coast nonattainment area tied to promulgation of a USEPA National Locomotive Rule. ARB, USEPA and participating railroads committed to develop this program, known as the South Coast Locomotives Program, by signing a Statement of Principles (SOP) in May 1997. Following the signing of the SOP, the railroads, USEPA, and ARB discussed improvements and refinements of this program. In July 1998, a second agreement was signed that affects the in-use locomotive fleet in the South Coast nonattainment area. That agreement is a Memorandum of Understanding (MOU) signed by the ARB and participating railroads, agreeing to a voluntary locomotive fleet average emissions program that will speed the introduction of new, lower-emitting engines in the South Coast Air Basin.

1. Emissions Inventory

The primary business of railroads is transportation of freight or passengers. Locomotives provide line-haul, local (short-line), switchyard, and passenger services. In California, line-haul transportation is the primary function of the Union Pacific Railroad Company, and the Burlington Northern and Santa Fe Railway Company. These companies transport goods between major urban centers, sometimes over 1,000 miles apart. Reliability is an important factor when transporting goods at large distances. Locomotive "down-times" could be very expensive and are the cause of a tremendous loss in revenue. Hence, line-hauls are well maintained, with remanufacture occurring every seven to eight years.

Locomotives are well maintained and typically have a long useful life. Line-hauls with engines over 3000 horsepower (hp) and no longer suitable for line-haul service are typically designated for other services out of California, or even out of the U.S. Line-hauls less than 3000 hp that are no longer suitable for line-haul services, are usually re-assigned to the short-line fleets, and subsequently to the switchyards. Short-lines have smaller engines than line hauls since these locomotives require less work, carry smaller loads, and travel shorter distances, generally under 200 miles. Short-lines consist of an older locomotive fleet, mostly predating the 1973 model year. Switch-yard locomotives are usually the oldest locomotives, and require the least amount of travel and work. Switchers typically distribute and re-arrange cars within the terminal and provide services within the state, usually remaining in the same geographical area.

There are approximately 20,000 locomotives in the U.S and about 1,200 (or six percent) are in California. Of these 1,200 locomotives, approximately 250 are used as locals, 200 are used in switchyards, 100 are passenger trains, and the remaining 650 are used as line-hauls.[1] Locomotives generated approximately 3 to 4 percent of the 1990 baseline NOx emissions in the South Coast Air Basin.[2] Table IV-1 lists baseline NOx emissions for 1990, 1996, and 2010. The baseline NOx emissions listed in Table IV-1 do not reflect USEPA nationwide emission standards for new and remanufactured locomotives, or the MOU for the in-use locomotive fleet in the South Coast nonattainment area.

Table IV-1
Baseline NOx Emissions [a]
(tons/day)

Area	1990	1996	2010
South Coast	30	28	26
Statewide	160	150	140

a) Emission estimates from the ARB's emission inventory.

2. Emission Standards

USEPA adopted emission standards for locomotives nationwide in December 1997. The standards take effect in the year 2000. Federal standards apply to locomotives originally manufactured from 1973 and any time they are manufactured or remanufactured. Electric locomotives, historic steam-powered locomotives, and locomotives originally manufactured before 1973 are not regulated. Table IV-2 contains the federal exhaust emission standards for locomotives. Emission standards for short-line and line-hauls are both based on the line-haul duty cycle.

Table IV-2 Federal Exhaust Emission Standards for Locomotives Beginning in 2000 for New Engines and at Time of Remanufacture				
Duty-cycle	**Gaseous and Particulate Emissions (g/bhp-hr)**			
	HC	**CO**	**NOx**	**PM**
	Tier 0 (1973 – 2001 model years)			
Line-haul duty-cycle	1.00	5.0	9.5	0.60
Switch duty-cycle	2.10	8.0	14.0	0.72
	Tier 1 (2002 – 2004 model years)			
Line-haul duty-cycle	0.55	2.2	7.4	0.45
Switch duty-cycle	1.20	2.5	11.0	0.54
	Tier 2 (2005 and later model years)			
Line-haul duty- cycle	0.30	1.5	5.5	0.20
Switch duty-cycle	0.60	2.4	8.1	0.24

USEPA, Final Emissions Standards for Locomotives, EPA420-F-97-048, December 1997

3. Control Technology

Although locomotives and their engines are expensive, they are designed to last a long time. Typical lifetimes are between 25 and 30 years. Over this life, they are overhauled several times and, perhaps, re-engined once. For the most part, locomotive engines are well maintained and the emissions associated with these engines typically remain the same over their lifetime.

The desire to improve fuel economy has influenced the development of more advanced locomotive technologies. Locomotive exhaust emission levels have generally been reduced with the development of new engine technologies. These technologies are somewhat similar to those for on-road heavy-duty vehicle control technology. Technologies include, but are not limited to, turbocharging and aftercooling for NOx control, and improved fuel injection and combustion chamber design for PM and HC control.

B. Project Criteria

The project criteria for locomotives under the Carl Moyer Program have been designed to provide districts with a list of minimum qualifications that must be met by applicants in order for a reduced-NOx locomotive project to qualify for funding. These criteria will provide districts and program operators with calculations that must be used for determining emission reductions and cost effectiveness resulting from reduced-NOx locomotive projects. Reduced-NOx locomotive engine projects that include new, repowered, or retrofitted locomotive engines will be considered and closely evaluated as qualifying for incentive funding. For the most part the criteria for selecting a project will depend on the amount of emission reductions, cost effectiveness, and the potential for the project to materialize within a realistic timeframe. New criteria have been added in order to normalize the selected project life of a locomotive project. In general, locomotive projects that meet the following criteria would qualify for funding.

- Any emission reductions achieved through the application of Carl Moyer Program funds cannot be credited toward compliance with the 1998 MOU in the South Coast;

- NOx reductions for all other districts must be beyond what is required by any federal, local regulations, or other legally binding document;

- Engines must be tested according to the most current USEPA test procedures for Locomotives.

- Pre-1973 model year (MY) locomotives – must test to 15 percent below uncontrolled baseline NOx emissions;

- 1973 and later MY locomotives – must test to Tier 1 or Tier 2 federal locomotive NOx standards;

- The acceptable maximum project life for calculating project benefits are as follows:

	Default without Documentation	Default with Documentation
A new locomotive project	20 years	30 years
A repower or retrofit project	20 years	30 years

  A different project life may be selected for approval by ARB staff. However sufficient documentation must be provided to ARB that supports the selected project life based on the actual remaining useful life.

- Reduced emission levels must be maintained for a minimum of 5 years;

- Seventy-five percent of estimated annual ton-miles traveled must occur in California;

- Seventy-five percent of estimated annual fuel consumption must occur in California; and

- Cost effectiveness must be no more than $13,000 per ton of NOx reduced.

C. Potential Types of Projects

Typical projects that would qualify for incentive funding under this program would include repowering a locomotive engine to a reduced-NOx configuration, use of a retrofit kit to lower engine NOx emissions, or the purchase of new, reduced-NOx engines. Repowering and retrofit projects are not limited, and could include use of control technologies that involve selective catalytic reduction (SCR), dual-fuel natural gas engine retrofits, or even turbocharging and aftercooling. There are also reduced-emission technologies (such as engine retrofit or new engine technologies) that hold promise for the future, but are not yet commercially available or certified for sale in California. ARB could approve test data for these technologies on a case-by-case basis. Beginning in the year 2000, when the federal standards go into effect, ARB could grant an experimental permit for a particular engine with certain technology to operate in California. However, all projects will be evaluated carefully to determine whether or not NOx reductions could indeed occur.

Reliability of a line-haul engine is extremely important. Since some of the control technologies are costly and have not been in wide use for locomotive engines, line-haul participation in the Carl Moyer Program is not expected until these technologies are proven effective and reliable on passenger, short-line, and switcher locomotive engines. Therefore, the ARB expects that reduced-NOx locomotive projects would be limited to passenger, short-line, or switchyard locomotives.

1. Repowers

Repowering could occur during engine remanufacture by exchanging a locomotive's old engine for a newer, lower-emission engine. According to these criteria the amount of funding granted and final project qualifications must be based on the amount of emissions reduced and a cost effectiveness of at most $13,000 per ton. There is no cap on the amount of funding received. However, in order to qualify for funding, locomotive engines must test to a reduced-NOx emissions level according to USEPA test procedures for locomotives. The reduced-NOx emission level must be maintained for a minimum of 5 years (project life).

Projects submitted for pre-1973 MY locomotives must show that engine NOx emissions will be reduced by a minimum of 15 percent below the uncontrolled baseline NOx emissions for pre-1973 MY, as listed in Table IV-3, below. Since there are no line haul locomotives in service in California with pre-1973 engines, these projects are likely to be for switchers. Projects submitted for 1973 and later MY locomotive engines must consist of engines tested to the federal Tier 1 or Tier 2 locomotive NOx standards as listed in Table IV-3, below. Engine tests must be conducted according to the Federal Test Procedures for locomotives. If additional funding is available beyond the calendar year 2001 to continue the Carl Moyer Program, criteria for project NOx limits will be modified to reflect the current federal standards.

Table IV-3
Baseline NOx Emission Factors and Maximum NOx Limits
(g/bhp-hr)

Engine Model Year	Source	Line-haul	Switcher
Pre-1973	Uncontrolled Baseline Emission Factor	16 [a, b]	16.9 [b]
1973 and later	Baseline Emission Factor	9.5	14.0
1973 and Later	NOx Limit – Federal Tier 1	7.4	11.0
	NOx Limit – Federal Tier 2	5.5	8.1

a. There are no line haul locomotives in service in California that are pre-1973, baseline emissions are listed for short-line locomotives only.
b. ARB emission rates are average estimates based on data provided by engine manufacturers.

2. Retrofits

Retrofit involves hardware modifications to the engine, so the engine has lower emissions. The conversion could occur by adding on control equipment to convert the engine to a reduced-NOx engine technology. This technology could include conversion to an alternative fuel locomotive engine. The amount of funding granted and the final project qualifications must be based on the amount of emissions reduced and a cost effectiveness of at most $13,000 per ton. Similar to repowers, in order to qualify for funding, locomotive engines must test to a reduced-NOx emissions level according to USEPA test procedures for locomotives. As with repowers, the tested emission level must be maintained for a minimum of 5 years (project life).

The maximum allowable NOx levels for line-haul and switchers using retrofit kits will be the same as for repowers. Projects submitted for pre-1973 MY locomotives must show that engine NOx emissions will be reduced by a minimum of 15 percent below the uncontrolled baseline NOx emissions as listed in Table IV-3, above. Projects submitted for 1973 and later MY locomotive engines must consist of engines tested to the federal Tier 1 or Tier 2 locomotive NOx standards as listed in Table IV-3, above. Once again, if additional funding is available beyond the calendar year 2001 to continue the Carl Moyer Program, criteria for project NOx limits will be modified to reflect the current federal standards.

2. Sample Project Application Forms

In order to qualify for incentive funds, districts will make applications available and solicit bids for reduced-emission projects from railroads. A sample application has been provided in Appendix E. The applicant must provide at least the following information, as listed in Table IV-4 below:

Table IV-4 Minimum Application Information Locomotive Projects	
1. Air District: 2. Applicant Demographics Company Name: Business Type: Mailing Address: Location Address: Contact Number: 3. Project Description Project Name: Locomotive Type: Engine Type: Vehicle Class: 4. Annual Ton-Miles: 5. Project Life (years): 6. Old Engine Information Horsepower Rating: Engine Make: Engine Model: Engine Year: 7. New Engine Information Horsepower Rating: Engine Make: Engine Model: Engine Year: Fuel Type:	8. NOx Reduction Incremental Cost Effectiveness Analysis Basis: (Mileage/Fuel/Hours of Operation) 9. VIN or Serial Number: 10. Application: (Repower, Retrofit or New) 11. Percent Operated in California: 12. Percent Operated in Air District: 13. Annual Diesel Gallons Used: 14. Fuel Consumption Rate: 15. NOx Emissions Reductions Baseline NOx Emissions Factor (g/bhp-hr): NOx Conversion Factors Used: Reduced NOx Emissions Factor (g/bhp-hr): Estimated Annual NOx Emissions Reductions: Estimated Lifetime NOx Emissions Reductions: 16. Cost ($) of the Base Engine: 17. Cost ($) of Certified LEV Engine: 18. PM Emissions Reductions Baseline PM Emissions Factor (g/bhp-hr): PM Conversion Factors Used: Reduced PM Emissions Factor (g/bhp-hr): Estimated Annual PM Emissions Reductions: Estimated Lifetime PM Emissions Reductions: 19. District Incentive Grant Requested:

D. Emission Reduction and Cost-Effectiveness

Control costs for locomotives differ greatly, depending on the particular scenarios and technology involved in any individual case. Preliminary cost evaluations of some reduced-NOx controls for locomotive engines indicate that the capital costs can be high (although less than purchasing a new engine), whereas some cost evaluations indicate that others could actually create a cost savings to locomotives. The amount of incentive funds granted depends on the amount of emission reductions. Only the portion of the incremental cost that meets a cost effectiveness of at most $13,000 per ton of NOx reduced will qualify for incentive funding.

1. Emission Reduction Calculation

Emission reductions for locomotives will be based on annual fuel consumption or hours of operation, and percent operated in California. If the applicant provides annual hours of operation, a fuel consumption rate must also be provided. Annual emissions must be estimated for the baseline engine and the new engine separately, taking into consideration baseline activity levels as compared with future activity levels. Annual emissions for each engine are calculated by multiplying the NOx emission factor by the energy consumption factor of 20.8 bhp-hr/gal, and the estimated annual fuel consumption. The results for both engines are subtracted, multiplied by the percent operated in California, then converted to tons.[3] If annual hours of operation are provided, the annual fuel consumption is calculated by multiplying the fuel consumption rate by the annual hours of operation. The following formulas must be used when calculating project NOx reductions.

Annual NOx Reductions (tons/year) =
[(Ann. Fuel Cons. * Fuel Cons. Factor * Baseline NOx Emissions) –
(Ann. Fuel Cons. * Fuel Cons. Factor * Reduced NOx Emissions)] *
% operated in CA * ton / 907,200 grams

Where,

Ann. Fuel Cons	= Estimated Annual Fuel consumption for the retrofitted engine(gal/year). If not known, provide annual hours of operation and a fuel consumption rate.
Fuel Cons. Factor	= Assumed Fuel Consumption Factor of 20.8 bhp-hr/gal
Baseline NOx Emissions	= NOx Emission factor from the old engine in g/bhp-hr
Reduced NOx Emissions	= NOx Emission factor from the new engine in g/bhp-hr
% operated in CA	= The percent of time operated in California
(ton/907,200 g)	Converts grams to tons

2. Cost Effectiveness Calculation

The cost-effectiveness is based on the incremental capital cost, any matching funds that were used to fund the project, the expected life of the project, the interest rate (five percent), and estimated annual NOx reductions in a particular district. The discount rate of five percent reflects the opportunity cost of public funds for the Carl Moyer Program. This is the level of earning that could be reasonably expected by investing state funds and is based on the most recent published interest rates on U.S. Treasury securities.

Incremental costs are determined by considering the difference between the capital cost to remanufacture an engine to its original configuration (without improved control technology) and the capital cost to repower/retrofit the engine with new control technology. The incremental capital cost is annualized using a five percent interest rate. Incremental costs are multiplied by a capital recovery factor, and divided by the annual NOx reductions in a district. This calculation will result in annualized project cost-effectiveness. Larger NOx reductions could result in better cost-effectiveness, depending on the amount of project incremental cost. Cost-effectiveness can be calculated using the following formulas:

Incremental Project Cost = **(Aft. Proj. Cap. Cost) - (Bef. Proj. Cap. Cost)**

Where,

Aft. Proj. Cap. Cost = capital costs for reduced-NOx engine
Bef. Proj. Cap. Cost = capital costs for the rebuilt engine without the upgrade

Maximum Amount Funded = (Incremental Project Cost) - (Match Funds)

Where,

Match Funds = Any matching funds

Capital Recovery Factor = $[(1 + i)^n (i)] / [(1 + i)^n - 1]$

Where,

i = discount rate (5 percent)
n = project life (at least five years)

Annualized Cost = [(Maximum Amount) + (Match Funds)] * (Capital Recovery Factor)

Cost-Effectiveness = (Annualized Cost) / (Annual NOx Reductions)

Where,

Annual NOx Reductions = Calculated NOx reductions (tons/year)

3. Examples

For the purposes of explaining the emission reduction and the cost effectiveness calculations from a locomotive engine project, two examples are presented below. The first example describes the calculations based on fuel consumption, whereas the second example provides an explanation for the calculations based on hours of operation.

Example 1 – Locomotive Engine Retrofit: Consider an operator faced with the opportunity to convert one locomotive engine, perhaps during the normal remanufacture period. In this case, the railroad applies for funding for a locomotive compressed natural gas retrofit kit for a 1972 short-line engine. The retrofit kit reduces uncontrolled emissions by 30 percent. Since it is usually about seven years until the next remanufacture, the project life is seven years. The railroad company estimates the remanufacture of the engine without the retrofit kit to be about $890,000. The upgrade, however, is more expensive, and will cost a total of $920,000. The railroad also estimates that the annual fuel consumption for this engine in California would be approximately 60,000 gals. Emission reductions are calculated using the formula listed in section D1, above, as follows:

Annual Fuel Consumption:	60,000 gals/year
Baseline NOx Emissions:	16.0 g/bhp-hr
Reduced NOx Emissions:	11.2 g/bhp-hr (30 percent reduction from 16.0 g/bhp-hr)
Fuel Cons. Factor:	20.8 bhp-hr/gal
% operated in CA:	100%
(ton/907,200 grams):	converts grams to tons

Estimated annual NOx reductions are:

[(60,000gal/year * 20.8 bhp-hr/gal * 16 g/bhp-hr) – (60,000 gal/year * 20.8 bhp-hr/gal 11.2 g/bhp-hr)] * 1 * ton / 907,200 g) = **6.6 tons/year**

Using the formulas in section D2, above, and the cost assumptions provided earlier in this section, the capital costs, the incremental costs and benefits can be calculated as follows:

Capital Costs for remanufacture without Upgrade	$ 890,000
Capital costs for remanufacture with retrofit kit	$ 920,000
District Matching funds	$ 0

Incremental Project Cost:	($ 920,000 - $ 890,000) = $ 30,000
Maximum Amount Funded:	($ 30,000 - $ 0) = $ 30,000
Capital Recovery Factor:	$[(1 + 0.05)^7 (0.05)]/[(1 + 0.05)^7 – 1] = 0.17$
Annualized Cost:	($ 30,000 + $ 0) * (0.17) = $ 5,100/ year
Cost Effectiveness:	($ 5,100 / year) / (6.6 tons/year) = **$ 773/ ton**

The cost effectiveness for the example is less than $13,000 per ton of NOx reduced. This project would qualify for the maximum amount of grant funds.

Example 2 – Locomotive Engine Replacement: Consider an operator faced with the opportunity to replace a short-line locomotive engine, perhaps during the normal remanufacture period. In this case, the railroad applies for funding for a short-line locomotive to replace a 1983 short-line engine (9.5 g/bhp-hr NOx) with a liquefied natural gas (LNG) engine (4.0 g/bhp-hr NOx). The railroad company estimates a project life of 20 years for the LNG engine. The railroad company also estimates the normal remanufacture costs for the engine to be about $890,000. The LNG upgrade, however, is more expensive, and will cost a total of $1.2 million. The railroad also estimates that the annual hours of operation for the new engine to be 1000 hours per year, with an average fuel consumption rate of 260 diesel equivalent gallons per hour. Emission reductions are calculated using the formula listed in section D1, above, as follows:

Annual Fuel Consumption:	1000 hrs/yr * 260 gals/hr = 260,000 gals
Baseline NOx Emissions:	9.5 g/bhp-hr
Reduced NOx Emissions:	4.0 g/bhp-hr
Energy Consumption Factor:	20.8 bhp-hr/gal
% operated in CA:	100%
(ton/907,200 grams):	converts grams to tons

Estimated annual NOx reductions are:
[(260,000 gal/year * 20.8 bhp-hr/gal * 9.5 g/bhp-hr) - (436,800 gal/year * 20.8 bhp-hr/gal * 4.0 g/bhp-hr)] * 1 * ton / 907,200 g = **16.6 tons/year**

Using the formulas in section D2, above, and the cost assumptions provided earlier in this section, the capital costs, the incremental costs and benefits can be calculated as follows:

Capital Costs for remanufacture without Upgrade	$ 890,000
Capital costs for LNG engine	$1,200,000
Matching funds	$ 0

Incremental Project Cost:	**$** 1,200,000 - $ 890,000 = $ 310,000
Maximum Amount Funded:	**$** 310,000 – $ 0 = $ 310,000
Capital Recovery Factor:	$[(1 + 0.05)^{20} (0.05)]/[(1 + 0.05)^{20} – 1] = 0.08$
Annualized Cost:	($ 310,000 + $ 0) * (0.08) = $ 24,875/ year
Cost Effectiveness:	($ 24,875 / year) / (16.6 tons/year) = **$ 1,498/ ton**

The cost effectiveness for the example is less than $13,000 per ton of NOx reduced. This project would qualify for the maximum amount of grant funds ($310,000).

E. Reporting and Monitoring

The district has the authority to conduct periodic checks or solicit operating records from the applicant that has received Moyer funds for each retrofitted/repowered locomotive engine. This is to ensure that the engine is operated as stated in the program application. The applicant must maintain operating records and have them available to the district upon request. Records must contain, at minimum, locomotive identification numbers, retrofit hardware model and serial numbers, estimated annual fuel consumption in the California, hours of operation in California, hours in idle, and maintenance/repair dates (or any type of servicing information), and any emission testing results. Records must be retained and updated throughout the project life and made available for district inspection.

F. References

1. Controlling Locomotive Emission in California: Technology, Cost-Effectiveness, and Regulatory Strategy, Chris Weaver and Douglas McGregor, Engine, Fuel, and Emissions Engineering, Inc., March 1995.

2. Locomotive Emission Study California Air Resources Board, Booz, Allen, & Hamilton, January 1991.

3. Emission Factors for Locomotives, USEPA, EPA420-F-97-051, December 1997.